

ACTIVITY CYCLES OF SOUTHERN ASTEROSEISMIC TARGETS

T. S. METCALFE, P. G. JUDGE

High Altitude Observatory, NCAR, P.O. Box 3000, Boulder, CO 80307

S. BASU

Department of Astronomy, Yale University, P.O. Box 208101, New Haven, CT 06520

T. J. HENRY

Department of Physics and Astronomy, Georgia State University, Atlanta, GA 30302

D. R. SODERBLOM

Space Telescope Science Institute, 3700 San Martin Dr., Baltimore MD 21218

M. KNÖLKER, M. REMPEL

High Altitude Observatory, NCAR, P.O. Box 3000, Boulder, CO 80307

Proceedings of Solar Analogs II

ABSTRACT

The Mount Wilson Ca HK survey revealed magnetic activity variations in a large sample of solar-type stars with timescales ranging from 2.5 to 25 years. This broad range of cycle periods is thought to reflect differences in the rotational properties and the depths of the surface convection zones for stars with various masses and ages. Asteroseismic data will soon provide direct measurements of these quantities for individual stars, but many of the most promising targets are in the southern sky (e.g., α Cen A & B, β Hyi, μ Ara, τ Cet, ν Ind), while long-term magnetic activity cycle surveys are largely confined to the north. In 2007 we began using the SMARTS 1.5-m telescope to conduct a long-term monitoring campaign of Ca II H & K emission for a sample of 57 southern solar-type stars to measure their magnetic activity cycles and their rotational properties when possible. This sample includes the most likely southern asteroseismic targets to be observed by the Stellar Oscillations Network Group (SONG), currently scheduled to begin operations in 2012. We present selected results from the first two years of the survey, and from the longer time baseline sampled by a single-epoch survey conducted in 1992.

Subject headings: stars: activity—stars: chromospheres—stars: oscillations—surveys

1. ASTROPHYSICAL CONTEXT

Astronomers have been making telescopic observations of sunspots since the time of Galileo, gradually building a historical record showing a periodic rise and fall in the number of sunspots every 11 years. We now know that sunspots are regions with an enhanced local magnetic field, so this 11-year cycle actually traces a variation in surface magnetism. Attempts to understand this behavior theoretically often invoke a combination of differential rotation, convection, and meridional flow to modulate the field through a magnetic dynamo (e.g., see Rempel 2006; Dikpati & Gilman 2006). Wilson (1978) was the first to demonstrate that many solar-type stars exhibit long-term cyclic variations in their Ca II H & K emission, analogous to the solar variations.

Significant progress in dynamo modeling could only occur after helioseismology provided meaningful constraints on the Sun's interior structure and dynamics (Brown et al. 1989; Schou et al. 1998). Variations in the mean strength of the solar magnetic field lead to significant shifts (~ 0.5 μ Hz) in the frequencies of even the lowest-degree p-modes (Libbrecht & Woodard 1990; Salabert et al. 2004). Space-based asteroseismology missions, such as MOST (Walker et al. 2003), CoRoT (Baglin et al. 2006), and Kepler (Borucki et al. 2007), as well as future ground-based networks like the Stellar Oscillations Network Group (SONG),

will soon allow additional tests of dynamo models using other solar-type stars (see Chaplin et al. 2007; Metcalfe et al. 2007). Ironically, many of the best targets for asteroseismology are stars in the southern sky, while long-term activity cycle surveys have largely been confined to the north.

2. SURVEY METHODOLOGY

In August 2007, we began a long-term Ca HK monitoring program for a sample of 57 southern solar-type stars using the 1.5-m telescope at CTIO. This survey will continue through July 2010 as an NOAO long-term observing program, supplemented by additional time from our collaborators at SMARTS institutions. By the end of the long-term program, we will either directly measure or provide firm lower limits on the cycle period for those stars with the shortest activity cycles. By comparing our observations with those from an earlier single-epoch survey (Henry et al. 1996), we will also establish interesting limits on the cycle period for those stars with the slowest variations in activity.

The single-epoch survey of Henry et al. (1996) contained a total of 1016 observations of 815 individual stars with visual magnitudes between 0.0 and about 9.0, which were observed using the *RC Spec* instrument on the CTIO 1.5-m telescope. Several sub-samples were defined, including the “Best & Brightest” (B) and “Nearby” (N) samples, which together

contain 92 individual stars with visual magnitudes between 0.0 and 7.9, and B–V colors that are approximately solar. We further restrict our sample to the 57 stars in the combined (B+N) sample that are brighter than $V=6$, the limiting magnitude of future ground-based asteroseismic observations by SONG (see Table 1). All of the most promising southern asteroseismic targets (α Cen A & B, β Hyi, μ Ara, τ Cet, 70 Oph A, ν Ind) are included in this B+N subsample.

The CTIO 1.5-m telescope is now operated by a consortium of about a dozen partners, known as SMARTS (Small and Moderate Aperture Research Telescope System). This consortium runs the telescope in queue mode, with observations collected by a trained technician and made available for download by the principal investigator. The technician cycles between the available instruments based on the demand for each during the semester. It is important to note that SMARTS operates the *only* southern telescope run in queue mode with an aperture and instrument that are appropriate for this project. Aside from a dedicated survey telescope like the one at Mount Wilson, SMARTS is the only option that makes such time-domain monitoring feasible.

3. INITIAL RESULTS

The S-index derived from our first two years of survey data are shown in Figure 1 for several stars with interesting variations over this short time baseline. The southern target HD 17051 (ι Hor) exhibits a steady rise from mid-2008 through early 2009, with the most recent data suggesting a possible reversal from peak activity in mid-2009. The active equatorial target HD 22049 (ε Eri) shows smooth variations from one season to the next, with a mean activity level comparable to that measured by the Mount Wilson and Lowell surveys. The moderately southern G0V star HD 165185 appears to have a maximum in activity in early 2009. The mean activity level

measured by Henry et al. (1996) is shown for each star as an open square near the left axis for reference. No longer-term trends are apparent for these three targets.

Similar plots for all of our survey targets are shown in Figures 2 & 3. The sample has been divided into subsets of low- and high-activity stars, each with a common vertical scale. Within each subset, the stars are displayed in three columns ordered by their HD number. Activity levels from the single-epoch survey of Henry et al. (1996) are again shown on the left to reveal longer-term trends, and targets that are included in the Mount Wilson (MWO) and Lowell (SSS) surveys are indicated at the upper right of each panel.

We performed least-squares linear fits to each of the data sets to quantify the significance of any increasing or decreasing trends over the first two years, with the results shown in Table 1. We found significant slopes (from 4.5 to 126 σ) for 85% of the targets, while the remaining 15% were statistically flat (from 1.4 to 3.8 σ). This is roughly consistent with the fraction found to be in a Maunder Minimum type phase by Henry et al. (1996). Significant trends are observed for the recent asteroseismic targets β Hyi (HD 2151, 7.3 σ), τ Cet (HD 10700, 8.4 σ), α Cen B (HD 128621, 116 σ), μ Ara (HD 160691, 8.8 σ), 70 Oph A (HD 165341, 64 σ), and ν Ind (HD 211998, 6.3 σ). No significant trend is yet seen for α Cen A (HD 128620, 1.7 σ).

This survey began with SMARTS time purchased by High Altitude Observatory through Georgia State University, and is currently supported under NOAO long-term program 2008B-0039. The National Center for Atmospheric Research is a federally funded research and development center sponsored by the U.S. National Science Foundation.

REFERENCES

- Baglin, A., Michel, E., Auvergne, M., & The COROT Team 2006, ESA-SP, 624, 34
 Borucki, W. J., et al. 2007, ASP. Conf, 366, 309
 Brown, T. M., Christensen-Dalsgaard, J., Dziembowski, W. A., Goode, P., Gough, D. O., & Morrow, C. A. 1989, ApJ, 343, 526
 Chaplin, W. J., Elsworth, Y., Houdek, G., & New, R. 2007, MNRAS, 377, 17
 Dikpati, M., & Gilman, P. A. 2006, ApJ, 649, 498
 Henry, T. J., Soderblom, D. R., Donahue, R. A., & Baliunas, S. L. 1996, AJ, 111, 439
 Libbrecht, K. G., & Woodard, M. F. 1990, Nature, 345, 779
 Metcalfe, T. S., Dziembowski, W. A., Judge, P. G., & Snow, M. 2007, MNRAS, 379, L16
 Rempel, M. 2006, ApJ, 647, 662
 Salabert, D., Fossat, E., Gelly, B., Kholikov, S., Grec, G., Lazrek, M., & Schmider, F. X. 2004, A&A, 413, 1135
 Schou, J., et al. 1998, ApJ, 505, 390
 Walker, G., et al. 2003, PASP, 115, 1023
 Wilson, O. C. 1978, ApJ, 226, 379

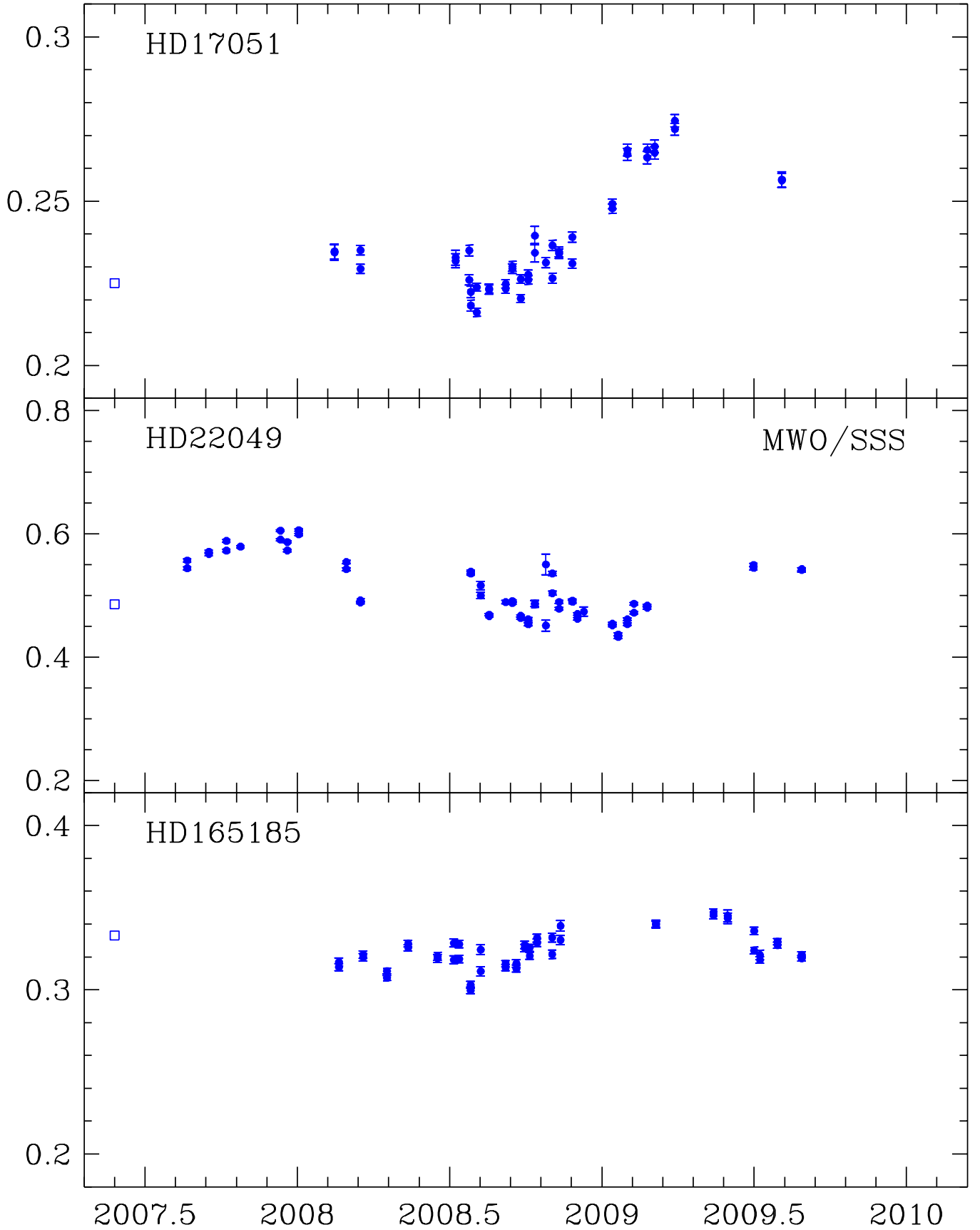


FIG. 1.— Early highlights from our activity cycle survey, showing the Mount Wilson S-index for several of our program stars during the first two years. The open square near the left axis shows the mean activity level measured by Henry et al. (1996) for comparison.

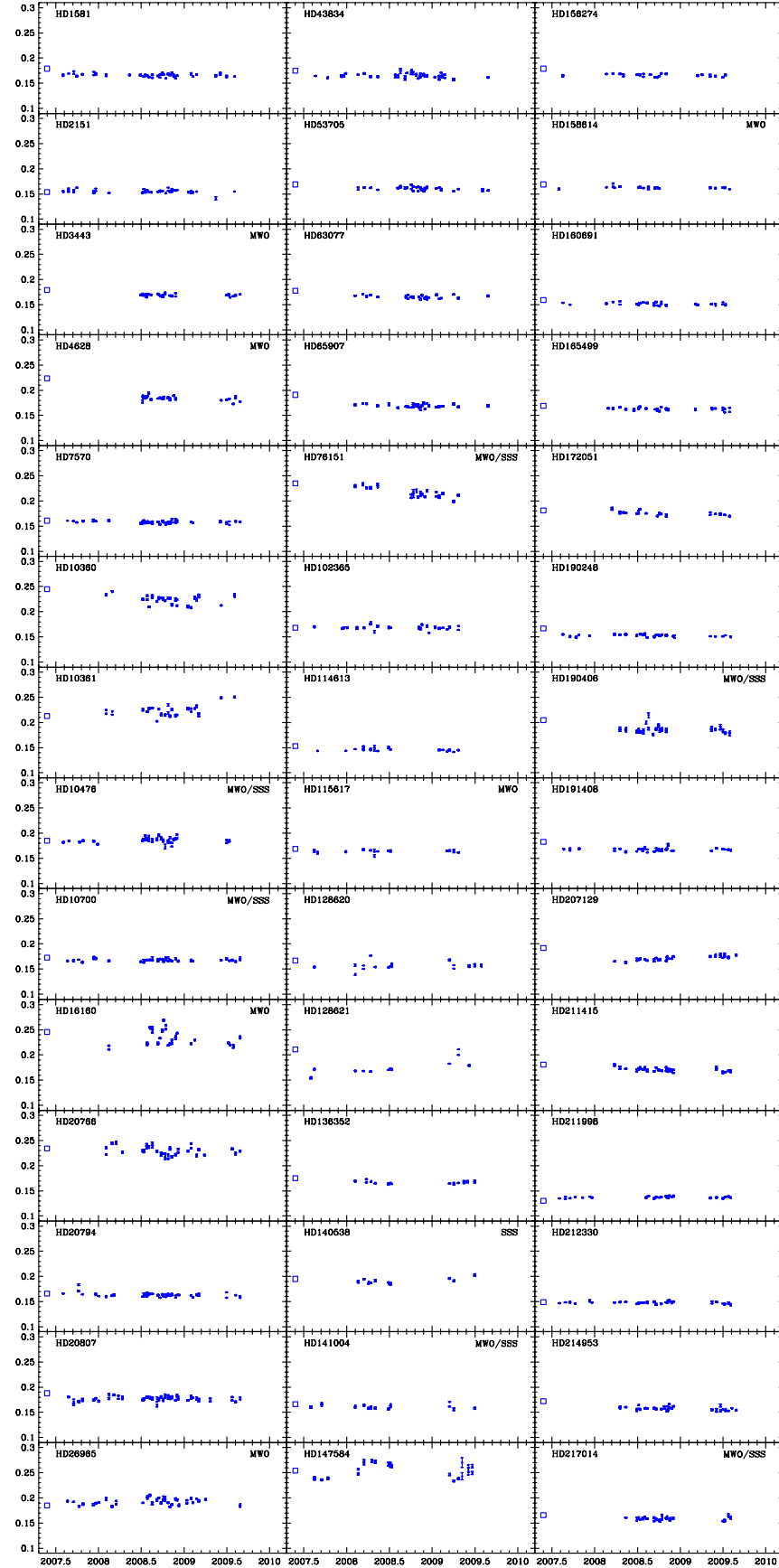


FIG. 2.— The first two years of data for low activity stars in our survey.

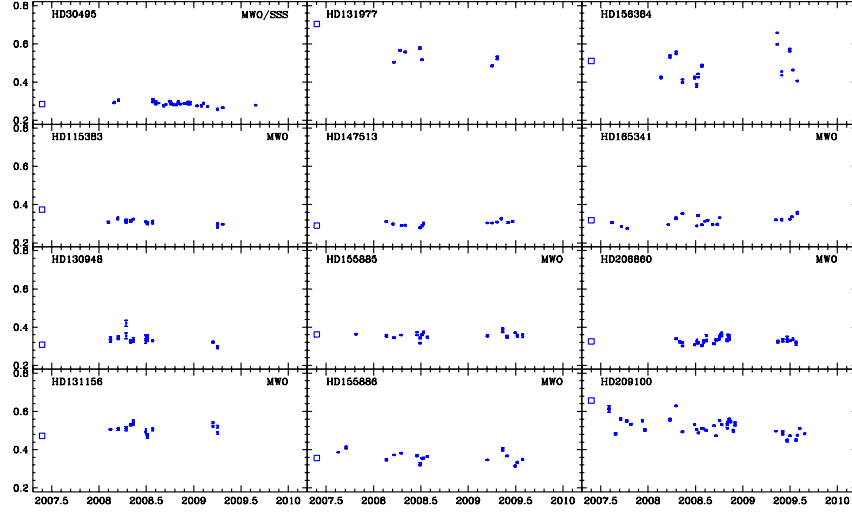


FIG. 3.— The first two years of data for high activity stars in our survey.

TABLE I
CHARACTERISTICS OF THE 57 STARS IN OUR SURVEY SAMPLE.

HD	RA(2000)	Dec(2000)	V	B-V	Trend?	HD	RA(2000)	Dec(2000)	V	B-V	Trend?
1581	00 20 04.3	-64 52 29	4.226	0.576	↘	131156 w	14 51 23.4	+19 06 02	4.700	0.730	↘
2151	00 25 45.1	-77 15 15	2.820	0.618	↘	131977	14 57 28.0	-21 24 56	5.723	1.024	↘
3443 w	00 37 20.7	-24 46 02	5.572	0.715	↘	136352	15 21 48.1	-48 19 03	5.652	0.639	→
4628 w	00 48 23.0	+05 16 50	5.742	0.890	↘	140538 s	15 44 01.8	+02 30 55	5.865	0.684	↗
7570	01 15 11.1	-45 31 54	4.959	0.571	↘	141004 ws	15 46 26.6	+07 21 11	4.422	0.604	→
10360	01 39 47.7	-56 11 34	5.900	0.800	↘	147513	16 24 01.3	-39 11 35	5.385	0.625	↗
10361	01 39 47.2	-56 11 44	5.800	0.860	↗	147584	16 28 28.1	-70 05 04	4.900	0.555	↗
10476 ws	01 42 29.8	+20 16 07	5.242	0.836	↗	155885 w	17 15 21.0	-26 36 10	5.330	0.860	→
10700 ws	01 44 04.1	-15 56 15	3.495	0.727	↘	155886 w	17 15 20.8	-26 36 09	5.290	0.850	↘
16160 w	02 36 04.9	+06 53 13	5.791	0.918	↘	156274	17 19 03.8	-46 38 10	5.330	0.770	↘
17051	02 42 33.5	-50 48 01	5.400	0.561	↗	156384	17 18 57.2	-34 59 23	5.910	1.040	↗
20766	03 17 46.2	-62 34 31	5.529	0.641	↘	158614 w	17 30 23.8	-01 03 47	5.314	0.715	→
20794	03 19 55.7	-43 04 11	4.260	0.711	↘	160691	17 44 08.7	-51 50 03	5.127	0.694	↘
20807	03 18 12.8	-62 30 23	5.239	0.600	↗	165185	18 06 23.7	-36 01 11	5.900	0.615	↗
22049 ws	03 32 55.8	-09 27 30	3.726	0.881	↘	165341 w	18 05 27.3	+02 30 00	4.026	0.860	↗
26965 w	04 15 16.3	-07 39 10	4.426	0.820	↗	165499	18 10 26.2	-62 00 08	5.473	0.592	↘
30495 ws	04 47 36.3	-16 56 04	5.491	0.632	↘	172051	18 38 53.4	-21 03 07	5.858	0.673	↘
43834	06 10 14.5	-74 45 11	5.080	0.714	↘	190248	20 08 43.6	-66 10 55	3.554	0.751	↘
53705	07 03 57.3	-43 36 29	5.559	0.624	↘	190406 ws	20 04 06.2	+17 04 13	5.788	0.600	→
63077	07 45 35.0	-34 10 21	5.363	0.589	↘	191408	20 11 11.9	-36 06 04	5.315	0.868	→
65907	07 57 46.9	-60 18 11	5.595	0.573	→	206860 w	21 44 31.3	+14 46 19	5.945	0.587	↗
76151 ws	08 54 17.9	-05 26 04	6.000	0.661	↘	207129	21 48 15.8	-47 18 13	5.579	0.601	↗
102365	11 46 31.1	-40 30 01	4.892	0.664	↘	209100	22 03 21.7	-56 47 10	4.688	1.056	↘
114613	13 12 03.2	-37 48 11	4.849	0.693	→	211415	22 18 15.6	-53 37 37	5.363	0.614	↘
115383 w	13 16 46.5	+09 25 27	5.209	0.585	↘	211998	22 24 36.9	-72 15 19	5.290	0.650	↗
115617 w	13 18 24.3	-18 18 40	4.739	0.709	↘	212330	22 24 56.4	-57 47 51	5.310	0.665	↘
128620	14 39 36.5	-60 50 02	0.010	0.710	→	214953	22 42 36.9	-47 12 39	5.988	0.584	↘
128621	14 39 35.1	-60 50 14	1.350	0.900	↗	217014 ws	22 57 28.0	+20 46 08	5.469	0.666	↘
130948	14 50 15.8	+23 54 43	5.863	0.576	↘

w/s: Mount Wilson / Lowell target